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APPLICATION FOR LETTERS PATENT

for

**ASSEMBLIES INCLUDING STACKED SEMICONDUCTOR DEVICES  
SEPARATED BY DISCRETE CONDUCTIVE ELEMENTS THEREBETWEEN,  
PACKAGES INCLUDING THE ASSEMBLIES, AND METHODS**

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**ASSEMBLIES INCLUDING STACKED SEMICONDUCTOR DEVICES  
SEPARATED BY DISCRETE CONDUCTIVE ELEMENTS THEREBETWEEN,  
PACKAGES INCLUDING THE ASSEMBLIES, AND METHODS**

**BACKGROUND OF THE INVENTION**

**Field of the Invention**

[0001] The present invention relates generally to semiconductor device assemblies, or so-called “multi-chip modules”, and, more specifically, to multi-chip modules in which two or more semiconductor devices are vertically stacked relative to one another. In particular, the present invention relates to semiconductor device assemblies in which the distances between adjacent stacked semiconductor devices are determined, at least in part, by the heights that discrete conductive elements, such as bond wires, tape-automated bond elements, or leads, protrude above an active surface of the lower of the adjacent, stacked semiconductor devices.

**Background of Related Art**

[0002] In order to conserve the amount of surface area, or “real estate”, consumed on a carrier substrate, such as a circuit board, by semiconductor devices connected thereto, various types of increased density packages have been developed. Among these various types of packages is the so-called “multi-chip module” (MCM). Some types of multi-chip modules include assemblies of semiconductor devices that are stacked one on top of another. The amount of surface area on a carrier substrate that may be saved by stacking semiconductor devices is readily apparent—a stack of semiconductor devices consumes roughly the same amount of real estate on a carrier substrate as a single, horizontally oriented semiconductor device or semiconductor device package.

[0003] Due to the disparity in processes that are used to form different types of semiconductor devices (*e.g.*, the number and order of various process steps), the incorporation of different types of functionality into a single semiconductor device has proven very difficult to actually reduce to practice. Even in cases where semiconductor devices that carry out multiple functions can be fabricated, multi-chip modules that include semiconductor devices with differing functions (*e.g.*, memory, processing capabilities, etc.) are often much more desirable since the

separate semiconductor devices may be fabricated and assembled with one another much more quickly and cost-effectively (*e.g.*, lower production costs due to higher volumes and lower failure rates).

**[0004]** Multi-chip modules may also contain a number of semiconductor devices that perform the same function, effectively combining the functionality of all of the semiconductor devices thereof into a single package.

**[0005]** An example of a conventional, stacked multi-chip module includes a carrier substrate, a first, larger semiconductor device secured to the carrier substrate, and a second, smaller semiconductor device positioned over and secured to the first semiconductor device. The second semiconductor device does not overlie bond pads of the first semiconductor device and, thus, the second semiconductor device does not cover bond wires that electrically connect bond pads of the first semiconductor device to corresponding contacts or terminals of the carrier substrate. As the bond pads of each lower semiconductor device are not covered by the next higher semiconductor device, spacing between the semiconductor devices is not important. Thus, any suitable adhesive may be used to secure the semiconductor devices to one another. Such a multi-chip module is disclosed and illustrated in U.S. Patent 6,212,767, issued to Tandy on April 10, 2001 (hereinafter "the '767 Patent"). As the sizes of the semiconductor devices of such a multi-chip module must continue to decrease as they are positioned increasingly higher on the stack, the heights of such multi-chip modules become severely limited.

**[0006]** Another example of a conventional multi-chip module is described in U.S. Patent 5,323,060, issued to Fogal et al. on June 21, 1994 (hereinafter "the '060 Patent"). The multi-chip module of the '060 Patent includes a carrier substrate with semiconductor devices disposed thereon in a stacked arrangement. The semiconductor devices of each multi-chip module may be the same size or different sizes, with upper semiconductor devices being either smaller or larger than underlying semiconductor devices. Adjacent semiconductor devices of each of the multi-chip modules disclosed in the '060 Patent are secured to one another with an adhesive layer. The thickness of each adhesive layer well exceeds the loop heights of wire bonds protruding from a semiconductor device upon which that adhesive layer is to be positioned. Accordingly, each adhesive layer prevents the back side of an overlying, upper semiconductor device from





## SUMMARY OF THE INVENTION

[0011] The present invention includes an assembly of stacked semiconductor devices in which a first semiconductor device is secured to a substrate, such as a circuit board, interposer, another semiconductor device, or leads, and includes bond pads that are electrically connected to corresponding contact areas of the substrate by way of discrete conductive elements. A second semiconductor device of the assembly is positioned over and secured to the first semiconductor device, with the back side of the second semiconductor device resting upon, but electrically isolated from the discrete conductive elements that extend over the active surface of the first semiconductor device.

[0012] The second semiconductor device, which may be larger, smaller, or the same size as the underlying, first semiconductor device, is secured over the first semiconductor device via an adhesive material, which may comprise a dielectric material. The distance between the first semiconductor device and the second semiconductor device is determined, at least in part, by the heights the discrete conductive elements protrude over the active surface of the first semiconductor device. Thus, the heights that discrete conductive elements protrude over the active surface of the lower semiconductor device of an adjacent stacked pair of semiconductor device, along with the thicknesses of the adjacent semiconductor devices, at least partially determines the overall thickness of a package including the assembled, stacked semiconductor devices.

[0013] The discrete conductive elements that extend over the first semiconductor device may be electrically isolated from the back side of the second semiconductor device by way of a dielectric coating on at least contacting portions of one or both of the discrete conductive elements and the back side of the second semiconductor device.

[0014] In one exemplary embodiment of an assembly including stacked semiconductor devices, the adhesive may fill the entire gap between the first and second semiconductor devices, substantially encapsulating the portion of each discrete conductive element located therebetween. The adhesive material may have a low enough viscosity (high liquidity), that air or other gases or gas mixtures are readily displaced, reducing the tendency for voids to form around discrete conductive elements or between the first and second semiconductor devices.

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[0015] When a low viscosity material, such as a conventional underfill material, is used to space the first and second semiconductor devices apart from one another, the first semiconductor device is secured and electrically connected to the underlying substrate by discrete conductive elements, such as bond wires. The second semiconductor device is positioned over the first semiconductor device, resting on and supported collectively by the discrete conductive elements that electrically connect bond pads of the first semiconductor device to their corresponding contact areas of the substrate. The second semiconductor device may be at least temporarily secured to the first semiconductor device by way of a small quantity of adhesive material, such as an adhesive polymer, solder flux, or the like, which may, for example, be placed on a surface of the first semiconductor device, the second semiconductor device, and/or one or more discrete conductive elements prior to positioning the second semiconductor device over the first semiconductor device. The low viscosity adhesive material may then be introduced between the first and second semiconductor devices.

[0016] The wetting properties of a low viscosity adhesive material may facilitate spreading thereof over the active surface of the first semiconductor device and the back side of the second semiconductor device, as well as capillary action, or “wicking” through the spaces between the first and second semiconductor devices and around the portions of discrete conductive elements located between the first and second semiconductor devices. Spreading of the adhesive material may be aided by application of heat thereto or by mechanical vibration of the assembly. When a fixed quantity of adhesive material that is smaller than a volume between the stacked first and second semiconductor devices (superimposed surface area times height between the devices) is used, the surface tension of the adhesive material may cause the second semiconductor device to be drawn onto the discrete conductive elements protruding above the active surface of the first semiconductor device and may also cause an even further decrease in the distance between the first and second semiconductor devices as the adhesive material spreads therebetween, thereby decreasing the overall height of the assembly. Curing of the adhesive material may cause shrinkage thereof, drawing the first and second semiconductor devices more closely to one another during curing. If the adhesive material is used to decrease the distance between the first and second semiconductor devices, it is preferred that a sufficient amount of

adhesive material be used to prevent delicate, raised discrete conductive elements, such as bond wires, from bending, kinking, distorting, or collapsing onto one another.

**[0017]** Alternatively, or in addition, the low viscosity adhesive material may expand somewhat as it cures, pushing the backside of the second semiconductor device away from the underlying discrete conductive elements to relieve stress on the discrete conductive elements or to electrically isolate the discrete conductive elements from the back side of the second semiconductor device.

**[0018]** The viscosity of the adhesive material may also be sufficient to prevent the adhesive material from flowing off of the active surface of the first semiconductor device. In addition the volume of a low viscosity adhesive material may be controlled so as to prevent the adhesive material from flowing off of the active surface of the first semiconductor device.

**[0019]** An adhesive material that has a relatively higher viscosity may be used in another exemplary embodiment of assembly including stacked semiconductor devices. While a higher viscosity adhesive material, such as a glob-top type encapsulant compound, may not substantially fill the space between the first and second semiconductor devices or substantially encapsulate the portions of discrete conductive elements that are located between the first and second semiconductor devices, a higher viscosity adhesive material may be used to support the second semiconductor device relative to an underlying first semiconductor device prior to curing of the adhesive material.

**[0020]** Due to its high viscosity, such an adhesive material may be applied to a portion of the active surface of the first semiconductor device prior to positioning the second semiconductor device thereover. Optionally, a relatively high viscosity adhesive material could be applied to a surface of a second semiconductor device prior to placement thereof over the first semiconductor device. Alternatively, the second semiconductor device may be positioned over the first semiconductor device, then a high viscosity adhesive material introduced therebetween.

**[0021]** When a relatively high viscosity adhesive material is used, a controlled amount of force or positive loading normal to the planes of the semiconductor devices may be applied to one or both of the active surface of the second semiconductor device or the bottom of the substrate in such a manner that the first semiconductor device and second semiconductor device are biased





## BRIEF DESCRIPTION OF THE DRAWINGS

[0027] In the drawings, which illustrate exemplary embodiments of various aspects of the present invention:

[0028] FIG. 1 is a schematic representation of one embodiment of an assembly incorporating teachings of the present invention;

[0029] FIGs. 2-8 are schematic representations depicting fabrication of the assembly shown in FIG. 1;

[0030] FIG. 9 is a schematic representation of a semiconductor device package including the assembly of FIG. 1;

[0031] FIG. 10 schematically depicts an assembly of the embodiment depicted in FIG. 1 that includes an additional semiconductor device;

[0032] FIG. 11 is a schematic representation of another embodiment of an assembly according to the present invention;

[0033] FIGs. 12-17 schematically depict fabrication of the assembly shown in FIG. 11; and

[0034] FIG. 18 is a schematic representation of yet another embodiment of an assembly of the present invention.

## DETAILED DESCRIPTION

[0035] With reference to FIG. 1, an exemplary embodiment of an assembly 10 incorporating teachings of the present invention is illustrated. As shown, assembly 10 includes a substrate 20 with two semiconductor devices 30a, 30b (collectively “semiconductor devices 30”) positioned thereover in stacked arrangement. As used herein, the term “semiconductor device” includes, without limitation, singulated semiconductor dies, as well as partial wafers and wafer-scale semiconductor substrates including multiple semiconductor dice.

[0036] The depicted substrate 20 is an interposer with a number of bond pads, which are referred to herein as contact areas 24, through which electrical signals are input to or output from semiconductor devices 30 carried upon or adjacent to a surface 22 of substrate 20. Contact areas

24 correspond to bond pads 34 on an active surface 32 of one of the semiconductor devices 30 positioned upon substrate 20.

**[0037]** A first semiconductor device 30a is secured to substrate 20 by way of a first adhesive element 26, such as a quantity of an appropriate thermoset resin, a quantity of pressure sensitive adhesive, an adhesive-coated film or tape, or the like. Bond pads 34 of first semiconductor device 30a communicate with corresponding contact areas 24 of substrate 20 by way of discrete conductive elements 38a, such as the illustrated bond wires, tape-automated bond (TAB) elements comprising traces on a flexible dielectric film, other thermocompression bonded leads, or other known types of conductive elements.

**[0038]** Second semiconductor device 30b is positioned over, or “stacked” on, first semiconductor device 30a. A back side 33 of second semiconductor device 30b rests upon discrete conductive elements 38a but is electrically isolated therefrom. Second semiconductor device 30b is secured to first semiconductor device 30a by way of a second adhesive element 36 interposed between and secured to active surface 32 of first semiconductor device 30a and back side 33 of second semiconductor device 30b. By way of example only, second adhesive element 36 may comprise a thermoplastic resin, a thermoset resin, an epoxy, a silicone, a polyurethane, a parylene, or any other suitable material that, upon curing, will adhere to and substantially maintain the desired relative positions of first and second semiconductor devices 30a, 30b.

**[0039]** Bond pads 34 of second semiconductor device 30b are electrically connected to corresponding contact areas 24 of substrate 20 by way of discrete conductive elements 38b. As with discrete conductive elements 38a, discrete conductive elements 38b may comprise bond wires, TAB elements, other thermocompression bonded leads, or any other known type of discrete conductive element for establishing the desired communication between a bond pad 34 and its corresponding contact area 24 of a substrate 20.

**[0040]** Assembly 10 may also include external connective elements 14 electrically coupled to contact areas 24 by vias and, optionally, conductive traces carried by substrate 20, as known in the art. External connective elements 14 may comprise, as depicted, solder balls or conductive pins, conductive plug-in elements, conductive or conductor-filled epoxy pillars,

anisotropically conductive adhesive, or any other conductive structures that are suitable for interconnecting assembly 10 with other, external electronic components.

[0041] Turning now to FIGs. 2-8, an exemplary method for fabricating assembly 10 is illustrated.

[0042] In FIG. 2, a substrate 20, in this case an interposer, is provided. Substrate 20 may be formed from silicon, glass, ceramic, an organic material (*e.g.*, FR-4 resin), metal (*e.g.*, copper, aluminum, etc.), or any other suitable material. Contact areas 24, shown in the form of terminal pads, are arranged on surface 22 of substrate 20 adjacent to a semiconductor device supporting region 23 of surface 22.

[0043] Next, as shown in FIG. 3, first semiconductor device 30a is positioned on and secured to supporting region 23 of surface 22 by way of first adhesive element 26. By way of example, first adhesive element 26 may comprise an adhesive coated structure, such as a polyimide film, or a quantity of adhesive material (*e.g.*, thermoset resin, thermoplastic resin, epoxy, etc.). Discrete conductive elements 38a, depicted as bond wires, are placed between bond pads 34 of first semiconductor device 30a and their corresponding contact areas 24 of substrate 20.

[0044] FIG. 4 shows discrete conductive elements 38a as having a dielectric coating 37 on at least portions thereof. Dielectric coating 37 may be formed from any suitable dielectric material, including a polymer or a dielectric oxide. When a polymer is used to form dielectric coating 37, a thin (*i.e.*, low viscosity) liquid polymer may be applied to at least portions of discrete conductive elements 38a by a variety of suitable processes, including, without limitation, dipping discrete conductive elements 38a into a quantity of the polymer, spray coating the polymer onto discrete conductive elements 38a, and dispensing a quantity of polymer on each discrete conductive element. Alternatively, a dielectric coating 37 comprising a metal oxide may be formed on discrete conductive elements 38a by exposing discrete conductive elements 38a to one or more oxidizing conditions, such as increased temperature, an oxygen-species rich environment, or the like. Dielectric material, such as a silicon oxide, a silicon nitride, or a silicon oxynitride, may also be deposited onto discrete conductive elements 38 to form a dielectric

coating 37 thereon. Of course, the deposition process used should be suitable for the type of dielectric material that is used to form dielectric coating 37.

**[0045]** FIG. 5 illustrates the application of a predetermined quantity of at least partially unconsolidated (*e.g.*, liquid, gel, etc.) adhesive material 35 onto active surface 32 of first semiconductor device 30a. Alternatively, adhesive material 35 could be applied to a back side 33 (FIG. 6) of a second semiconductor device 30b (FIG. 6) prior to placement of second semiconductor device 30b over first semiconductor device 30a. Adhesive material 35 may have sufficient viscosity or surface tension to resist flowing off of active surface 32. As illustrated, the viscosity of adhesive material 35 may permit a quantity thereof to spread out somewhat when placed on active surface 32, while remaining relatively thick in a vertical dimension. By way of example only, adhesive material 35 may comprise a thermoplastic resin, a thermosetting resin, an epoxy, a silicone, a silicone-carbon resin, a polyimide, or a polyurethane.

**[0046]** As depicted in FIG. 6, second semiconductor device 30b is aligned with and positioned over first semiconductor device 30a and placed on adhesive material 35. The weight of second semiconductor device 30b, the force of a pick and place device that is used to align, position, and place second semiconductor device 30b, or a combination thereof may cause adhesive material 35 to be spread laterally over active surface 32 of first semiconductor device 30a. Adhesive material 35 may extend fully or partially between first and second semiconductor devices 30a and 30b. Once second semiconductor device 30b has been positioned over first semiconductor device 30a, adhesive material 35 may at least partially encapsulate discrete conductive elements 38a. Alternatively, discrete conductive elements 38a may contact a back side 33 of second semiconductor device 30b and be electrically isolated therefrom by other means, such as by way of a dielectric coating on portions or all of either discrete conductive elements 38a or back side 33.

**[0047]** Some nonconductive adhesive materials 35, such as those available from Dexter Corporation of Industry, California, as QUANTUM die attach and thermal adhesives, are thick (*i.e.*, have high viscosities at room, or ambient temperature) while becoming thinner (*i.e.*, less viscous) upon being heated to temperatures that are less than their curing temperatures. Thus, upon being subjected to increased temperatures, these adhesive materials 35 will draw second

semiconductor device 30b toward first semiconductor device 30a. Upon reaching their cure temperatures, these materials will polymerize and maintain the spacing between first semiconductor device 30a and second semiconductor device 30b.

**[0048]** Additional normal force or loading, represented by arrow F, may be applied to one or both of second semiconductor device 30b, as shown in FIG. 7, and first semiconductor device 30a to bias first and second semiconductor devices 30a and 30b toward one another and to cause adhesive material 35 to spread even more. Such force or loading may be applied mechanically (*e.g.*, with a die attach machine) or by way of one or more bursts of air or gas under positive pressure. The yield strength of the plurality of discrete conductive elements 38a disposed between first and second semiconductor devices 30a and 30b is preferably sufficient to withstand the application of biasing force oriented substantially perpendicularly relative to the planes in which the substantially mutually parallel first semiconductor device 30a and second semiconductor device 30b are located and, thus, to prevent discrete conductive elements 38a from being bent, kinked, or otherwise deformed or from collapsing onto one another.

**[0049]** Once regions of back side 33 of semiconductor device 30b, which are depicted in FIGs. 5-10 as being at least partially coated with dielectric material 39 (*e.g.*, a polymer, oxide, nitride, oxynitride, etc.) to further ensure electrical isolation of second semiconductor device 30b from discrete conductive elements 38a, are in contact with the uppermost portions of discrete conductive elements 38a, adhesive material 35 may be cured or otherwise hardened, or permitted to cure or harden, as appropriate for the type of material used, to form second adhesive element 36. Of course, thermoplastic adhesive materials may harden upon cooling, while other types of adhesive materials 35 may be cured in a manner that depends upon the type of curable adhesive material 35 employed. By way of example only, snap curing processes, heat curing processes, UV curing processes, microwave curing processes, or any suitable combination thereof (*e.g.*, UV curing an exposed, outer portion of adhesive material, then heat curing the interior portions thereof) may be used to cure a curable adhesive material 35.

**[0050]** Next, as shown in FIG. 8, discrete conductive elements 38b may be positioned between bond pads 34 of second semiconductor device 30b and corresponding contact areas 24 of substrate 20 to electrically connect bond pads 34 and contact areas 24.



[0054] A second semiconductor device 30b is positioned over first semiconductor device 30a, with a back side 33 of second semiconductor device 30b resting upon, but electrically isolated from top portions of discrete conductive elements 38a. A second adhesive element 36' secures back side 33 of second semiconductor device 30b to an active surface 32 of first semiconductor device 30a. As depicted, second adhesive element 36' may substantially encapsulate portions of discrete conductive elements 38a located between first semiconductor device 30a and second semiconductor device 30b. By way of example, second adhesive element 36' may comprise a two-stage epoxy, a thermoset resin, a silicone, an epoxy, a polyimide, or a parylene, or any other material that, upon curing, will substantially maintain the distance between active surface 32 of first semiconductor device 30a and back side 33 of second semiconductor device 30b.

[0055] Discrete conductive elements 38b electrically connect bond pads 34 of second semiconductor device 30b and their corresponding contact areas 24' of substrate 20'. Again, bond wires, TAB elements, other thermocompression bonded leads, or the like may be used as discrete conductive elements 38b.

[0056] An example of the formation of assembly 10' is shown in FIGs. 12-17.

[0057] In FIG. 12, a substrate 20' is provided. Substrate 20' includes a semiconductor device supporting region 23' on a surface 22' thereof and contact areas 24' exposed to surface 22' and positioned proximate to supporting region 23'. At least some of contact areas 24' correspond to bond pads 34 (FIG. 11) of a semiconductor device 30a, 30b to be positioned over substrate 20'.

[0058] FIG. 13 shows a first semiconductor device 30a being positioned over supporting region 23' and secured thereto with a first adhesive element 26. In addition, FIG. 13 depicts the electrical connection of bond pads 34 of first semiconductor device 30a to corresponding contact areas 24' of substrate 20' by way of discrete conductive elements 38a.

[0059] Second semiconductor device 30b is positioned on the uppermost portions of discrete conductive elements 38a, as shown in FIG. 14. Second semiconductor device 30b and discrete conductive elements 38a contacting back side 33 thereof may be electrically isolated from one another by way of dielectric coatings 37 on at least portions of discrete conductive elements



38a, as depicted in FIG. 4, or by way of a dielectric layer 39' on at least portions of back side 33 of second semiconductor device 30b that will contact discrete conductive elements 38a.

[0060] Referring now to FIG. 15, a predetermined quantity of at least partially unconsolidated (*i.e.*, liquid, gel, etc.) adhesive material 35' may be introduced between active surface 32 of first semiconductor device 30a and back side 33 of second semiconductor device 30b. The viscosity of adhesive material 35' preferably permits adhesive material 35' to wick, or flow between, active surface 32 and back side 33 by capillary action. Accordingly, known underfill materials (*e.g.*, thermoset resins, two-stage epoxies, etc.) are examples of materials that are suitable for use as adhesive material 35'. Upon hardening or curing, adhesive material 35' forms second adhesive element 36'.

[0061] Adhesive material 35' may be cured or otherwise hardened by an appropriate process or combination of processes, depending, of course, on the type of adhesive material 35' employed. By way of example only, snap curing processes, heat curing processes, UV curing processes, microwave curing processes, or any appropriate combination thereof may be used.

[0062] Once adhesive material 35' has sufficiently cured or hardened, known processes may be employed to place discrete conductive elements 38b, such as bond wires, TAB elements, or other thermocompression bonded leads, between bond pads 34 of second semiconductor device 30b and corresponding contact areas 24' of substrate 20', as illustrated in FIG. 16.

[0063] As shown in FIG. 17, at least portions of assembly 10' may be encapsulated, or packaged, as known in the art. By way of example, a protective encapsulant 40' may be formed by glob top encapsulation techniques employing suitable glob top encapsulant materials. Alternatively, other packaging techniques, including, without limitation, transfer molding, pot molding, and stereolithography, may be employed.

[0064] Turning now to FIG. 18, another exemplary embodiment of assembly 10" of the present invention is illustrated. Assembly 10" includes a substrate 20" in the form of leads 21", a first semiconductor device 30a with which leads 21" of substrate 20" are associated, and discrete conductive elements 38a", in the form of TAB elements, electrically connecting bond pads 34 of first semiconductor device 30a and corresponding contact areas 24" on leads 21". Discrete conductive elements 38a" are electrically isolated from first semiconductor device 30a by way of

a dielectric film 39" therebetween, such as a thin layer of a dielectric polymer (e.g., polyimide), silicon oxide, silicon nitride, or silicon oxynitride, which may be formed by known processes.

[0065] Assembly 10" also includes a second semiconductor device 30b positioned upon portions of discrete conductive elements 38a" in electrical isolation therefrom, as well as an adhesive element 36" positioned between an active surface 32 of first semiconductor device 30a and a back side 33 of second semiconductor device 30b. Bond pads 34 of second semiconductor device 30b communicate with corresponding contact areas 24" of substrate 20" by way of discrete conductive elements 38b, which are depicted as being bond wires, positioned therebetween.

[0066] As another alternative, an assembly incorporating teachings of the present invention may include a substrate which comprises leads-over-chip (LOC) type leads, which extend over a portion of an active surface of at least one stacked semiconductor device upon which at least one other semiconductor device is stacked.

[0067] Although the foregoing description contains many specifics, these should not be construed as limiting the scope of the present invention, but merely as providing illustrations of some exemplary embodiments. Similarly, other embodiments of the invention may be devised which do not depart from the spirit or scope of the present invention. Features from different embodiments may be employed in combination. The scope of the invention is, therefore, indicated and limited only by the appended claims and their legal equivalents, rather than by the foregoing description. All additions, deletions, and modifications to the invention, as disclosed herein, which fall within the meaning and scope of the claims are to be embraced thereby.